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San Diego

ISTEF Passive Imaging Programs

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IDA

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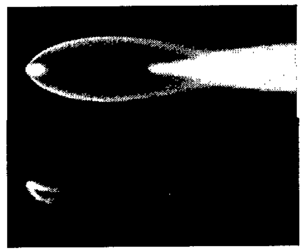
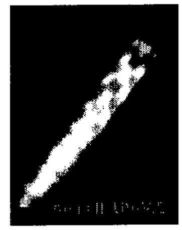
Overview

- Plume Observations
  - Illustration of ISTEF capability for multi-band, long focal length observations
  - Truth data for model improvements
    - Atlas II, Delta II as surrogates
  - Summary of analysis results
    - Aero Optics, Inc.
    - IDA / GWU



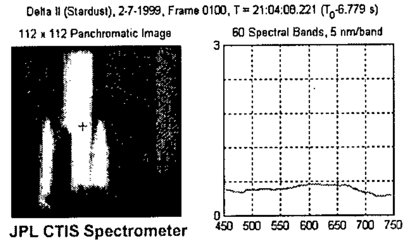


- Support / cooperation with other BMDO / DOD projects
  - Example missions and results
  - Candidate missions for the future

- Visiting Experiments
  - Innovative Sensor Technology
  - Example results
  - Future plans

THAAD FT-08 Target

Delta II (Stardust), 2-7-1999, Frame 0100, T = 21:04:08.221 (T_0-6.779 s)



JPL CTIS Spectrometer

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Multispectral Plume Movie

Atlas A7050 3/16/98

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MWIR
3.67-3.78 μm

UV-VIS
.386-.396
and
.483-.493
μm

LWIR
7.8-8.8 μm

NIR
0.9-1.1
μm

(Double click anywhere on image to play movie)

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MWIR

- Example: 256 x 256 x 12 bit
- 1.4 x 10^{-16} W/cm^2 NEFD at aperture
- Upgrade: High res 640 x 512 x 14 bit
- High frame rates at full window
- Sub-window rates to 4000 fps

UV-VIS

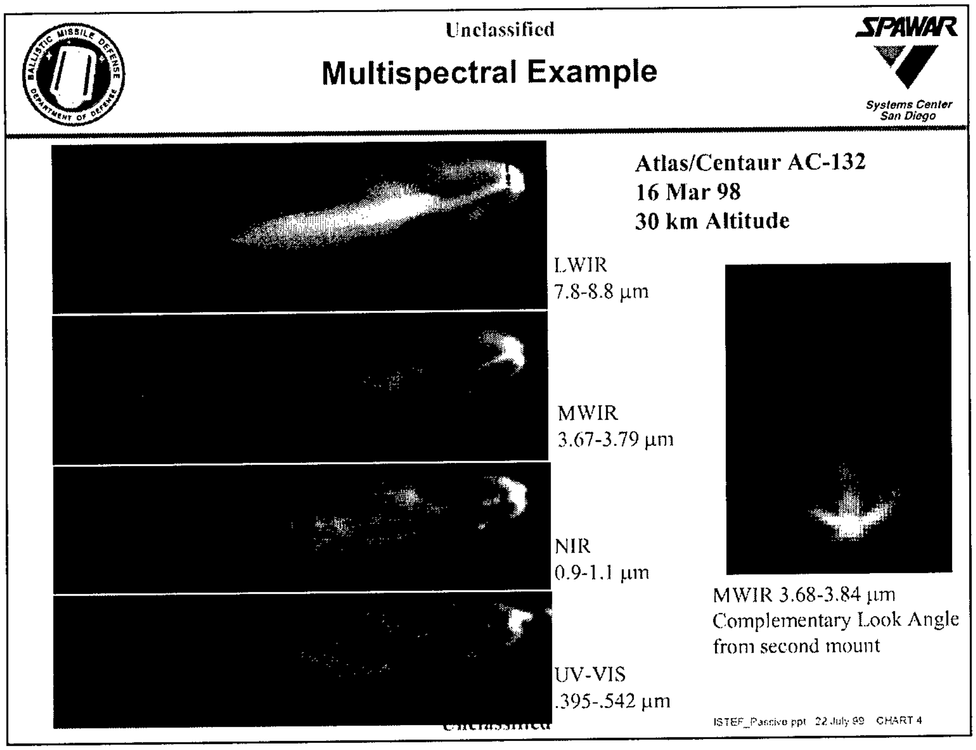
- Xybion 350 camera
- Hamamatsu intensifier
- 300-600 nm spectral range
- filters for sub-bands

LWIR

- Co-boresighted with MWIR
  - KTM with 24” optics
- JPL QWIP
- 256 x 256 x12 bit

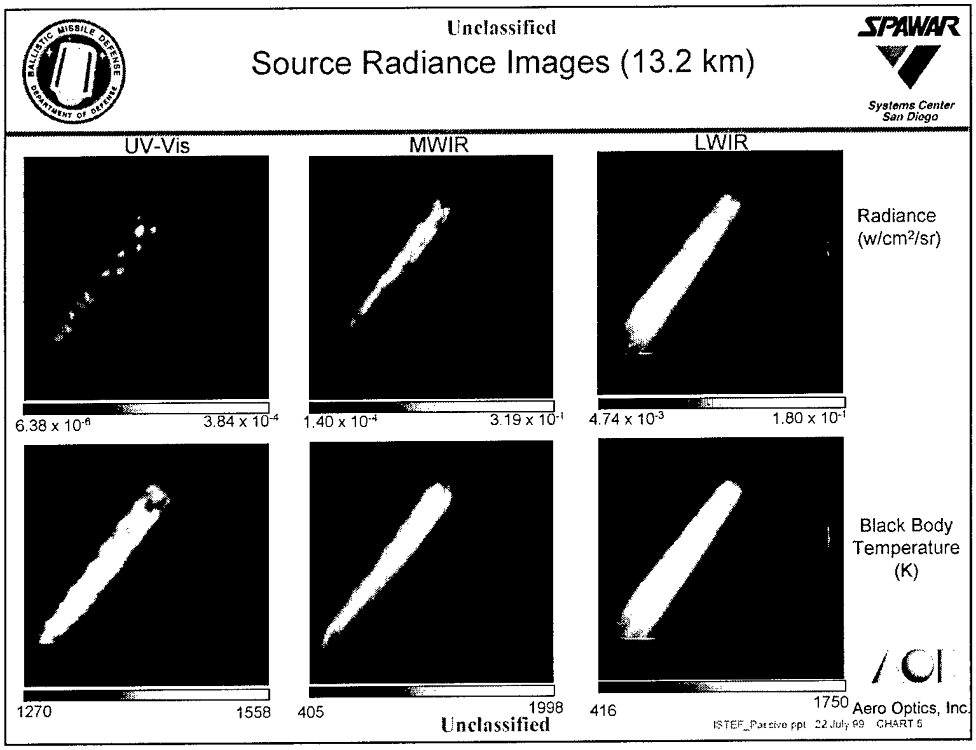
NIR

- Co-boresighted with UV-VIS
  - KTM with 24” optics



Example Multispectral Plume at 30 km Altitude

Intensity images have been roughly scaled and contrast adjusted to compare observed structure. The complex three nozzle plume is illustrated in the complementary angle image in MWIR. The stronger booster plumes have forced the center sustainer plume to split in two, yielding a "pitch-fork" shape. This structure is normal to the images at left.



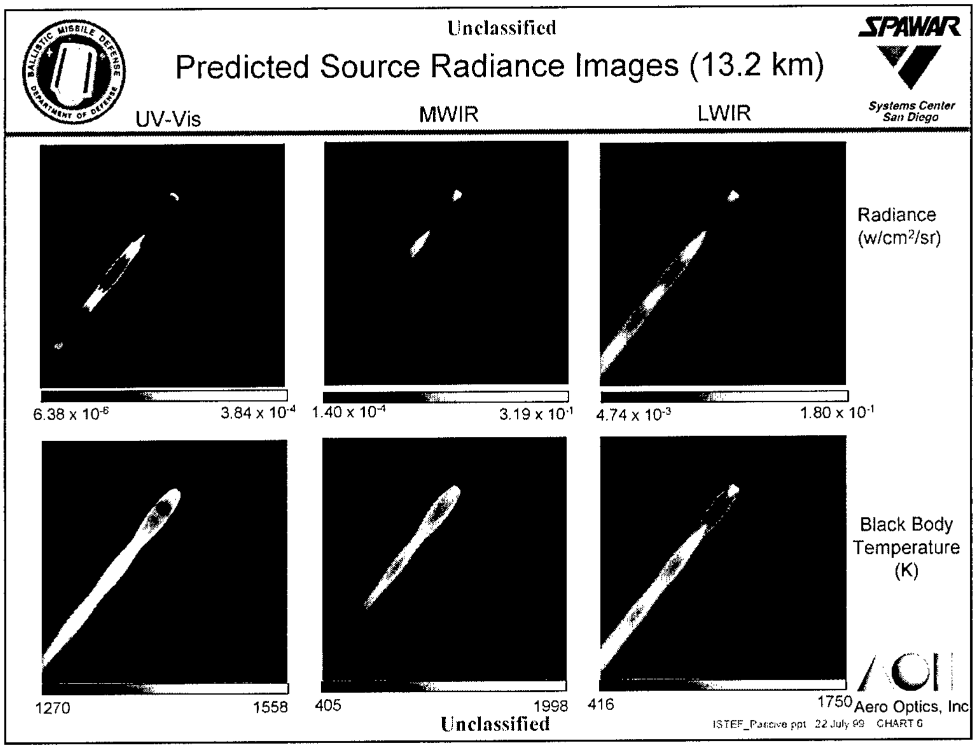
Images at TAL=86.7, Altitude=13.2 km

The images in each band reveal a complex flow structure due to plume-plume and plume-atmosphere interactions. The structure includes both outer and inner compression zones joined by diagonal reflected shocks. The UV-Vis structure differs from the MWIR/LWIR structure in that the initial cell is less bright than subsequent cells.

The histograms in each band reveal the distribution of plume brightness above the background (lower counts, maximum populations). The distribution is markedly different in each band.

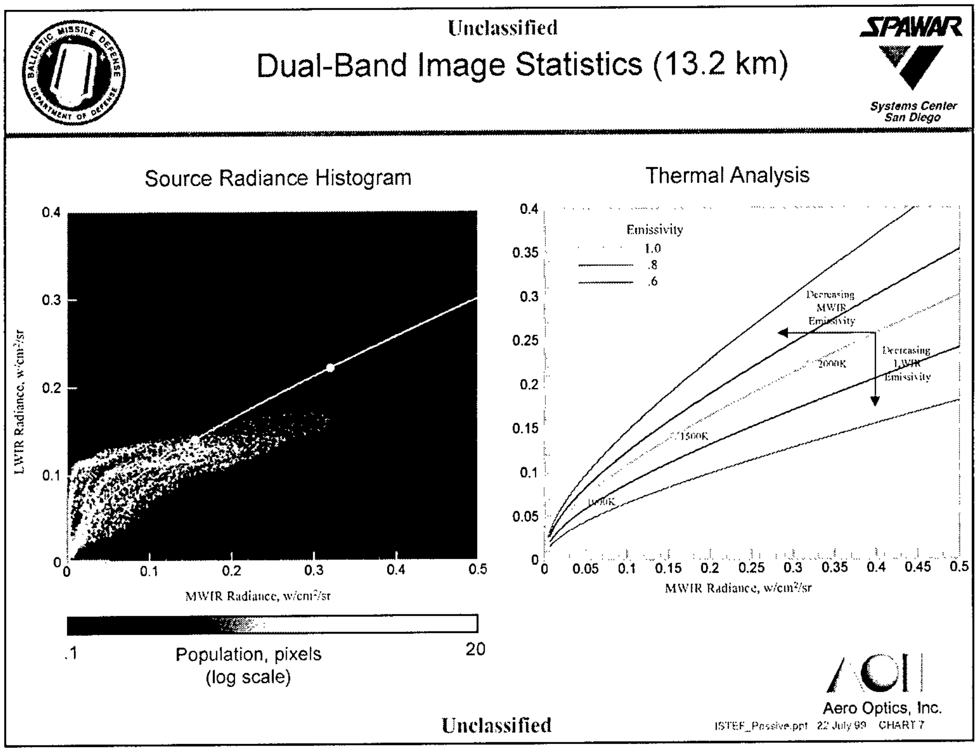
Instrument calibration factors (counts to radiance) were applied to the resampled/registered images to obtain apparent radiances (at the sensor aperture) and equivalent black-body radiometric temperatures. For each band, the background radiometric temperature (determined from the image histogram most populous value) is greater than the natural background temperature and is attributed to instrument optical/electronic effects.

Atmospheric attenuation factors (from MODTRAN) were applied to the apparent radiance images to obtain source radiances and equivalent black-body radiometric temperatures. Band-to-band differences in plume radiometric temperatures are attributed principally to differences in effective emissivity (LW vs. MW) or to non-thermal (chemical) effects (UV vs. MW). Note that the plume radiometric temperature decays much more slowly in the UV-Vis than in the MWIR or LWIR.



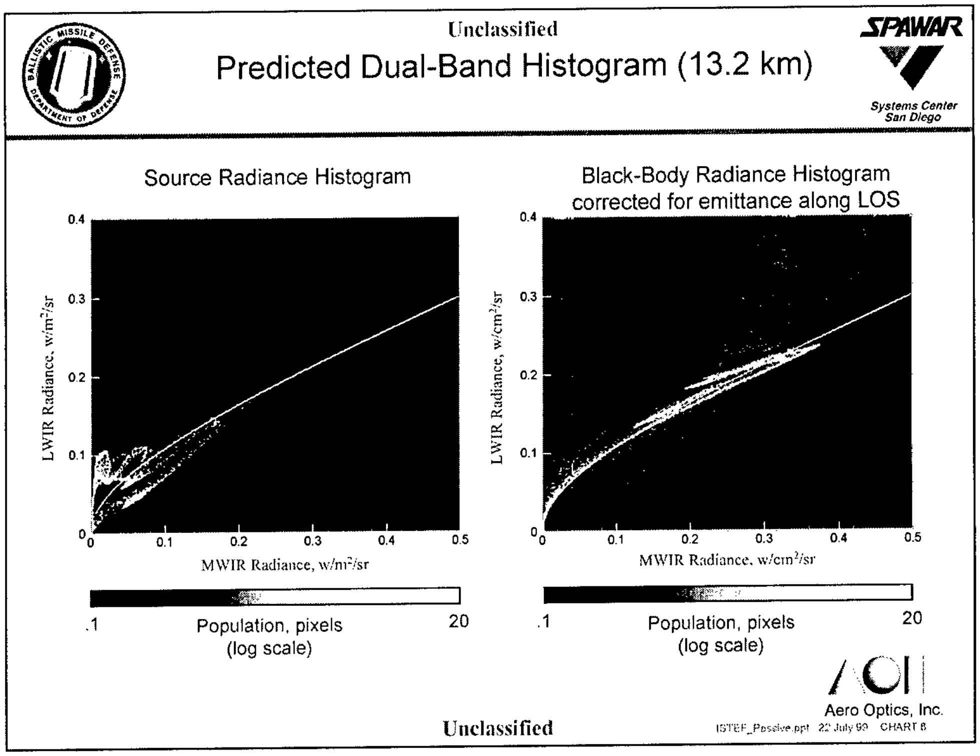
Predicted Source Radiance Images (13.2 km)

The standard plume codes (SPF/SIRRM) were used to predict source radiance images for a single-equivalent nozzle at the equivalent flight condition and aspect angle. Comparisons with the measured image features reveal the expected differences in shock structure and plume width due to multi-nozzle plume interactions not included in the code. The predicted and measured radiance levels were generally similar for the MWIR and LWIR but significantly different for the UV-Vis (predicted >> measured).



Dual-Band Image Statistics (13.2 km)

The multiband common image grid enables the investigation of pixel-to-pixel relative radiances and spectral/spatial correlation statistics. A dual-band histogram indicates the degree of correlation between the pixel radiances in two bands. The LW/MW histogram reveals a broad distribution about the locus of black-body emission shown as the blue line. The distribution about a single locus is due to variations in LW/MW relative plume emittance. These variations can be investigated by mapping selected histogram sub-regions back onto physical space.



Predicted Dual-Band Histogram (13.2 km)

Standard-code predictions (SPF/SIRRM) of the dual-band radiance imagery were used to generate synthetic histograms for comparison-to and diagnosis-of the measurement-based histograms. The synthetic LW/MW radiance statistics are again broadly distributed about the locus of black-body emission. The equivalent black-body radiance statistics (determined from the radiance/emittance ratio for each pixel and band) are (as expected) narrowly distributed about the black-body locus (blue line). The distribution is attributed to nonuniform path properties through the computed plume.

AOI SUMMARY

An initial assessment of calibrated multiband imagery and statistics has been completed, including:

- spatial structure, band differences, altitude effects
- band/time and band/band histograms and features
- radiometric temperatures, differences, mechanisms

• Additional assessments to be reported

- image temporal structure and statistics
- active vs. passive image features
- code predictions, comparisons, assessments

The power and utility of plume multispectral imaging was demonstrated by analysis of ISTEF multiband data for an Atlas plume. Multispectral image data enable unprecedented insight into the plume structure and radiative mechanisms which can be exploited for both scientific and systems applications. This work represents only the initial findings from an ongoing investigation.

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Effective Plume Temperatures in the UV

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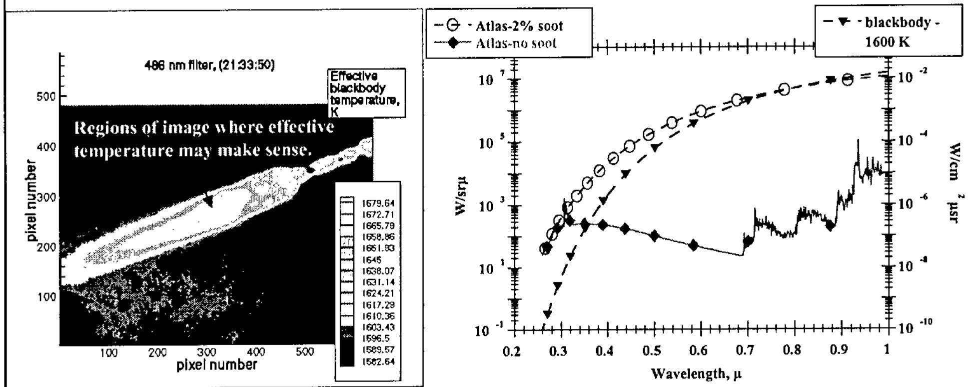

At 486, 390, 310 nm the center region of the plume has the same temperature of 1600 K. This is consistent with Earlier calculations shown above.

The George Washington University

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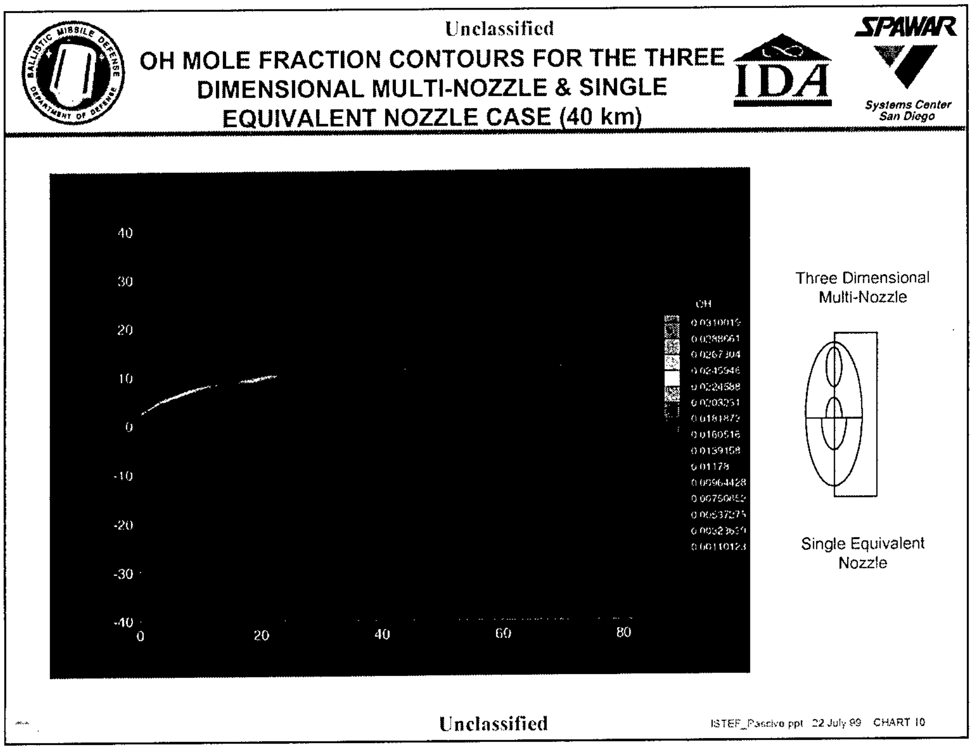
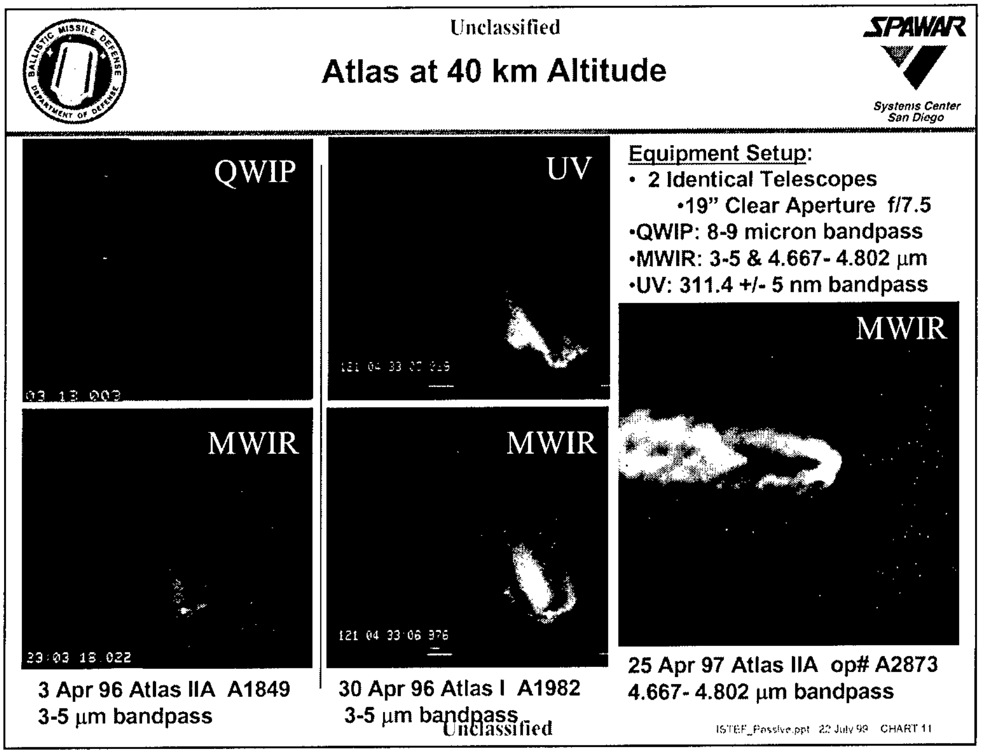


Example of Model Prediction

This prediction of an OH "shell" and the resulting radiance at 306 nm has not been observed. The lower half represents a single equivalent nozzle, with the upper half representing the multi-nozzle case.



Observation at 40 km

The UV data observed does not match the model prediction. Instead, the right portion of the plume has significantly lower radiance than the left. This may be due to the very rich asymmetrical turbo pump exhaust which merges with the right side booster plume.

The other bands are included for comparison. This set of images illustrates one case where the UV signature is different than the other bands.

IDA Conclusions:

ISTEF Data sets Are The Most Challenging Ever Presented To The Plume Modeling Community.

- The utility of a commercial CFD code in simulating a 3-D, chemically reacting plume flow has been demonstrated.
- The SEN flow/radiation simulated images do not match the image data.
- Simulated images give reasonable signal level agreement with data
  - in 3-5µ band ("old"-SIRRM)
  - in 0.310µ - problems identified with "old" SPURC OH kinetics model
  - DoD blessed radiation models need more scrutiny.

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High Altitude Dynamic Non-Uniformities in Extended Plume

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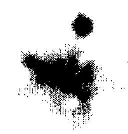
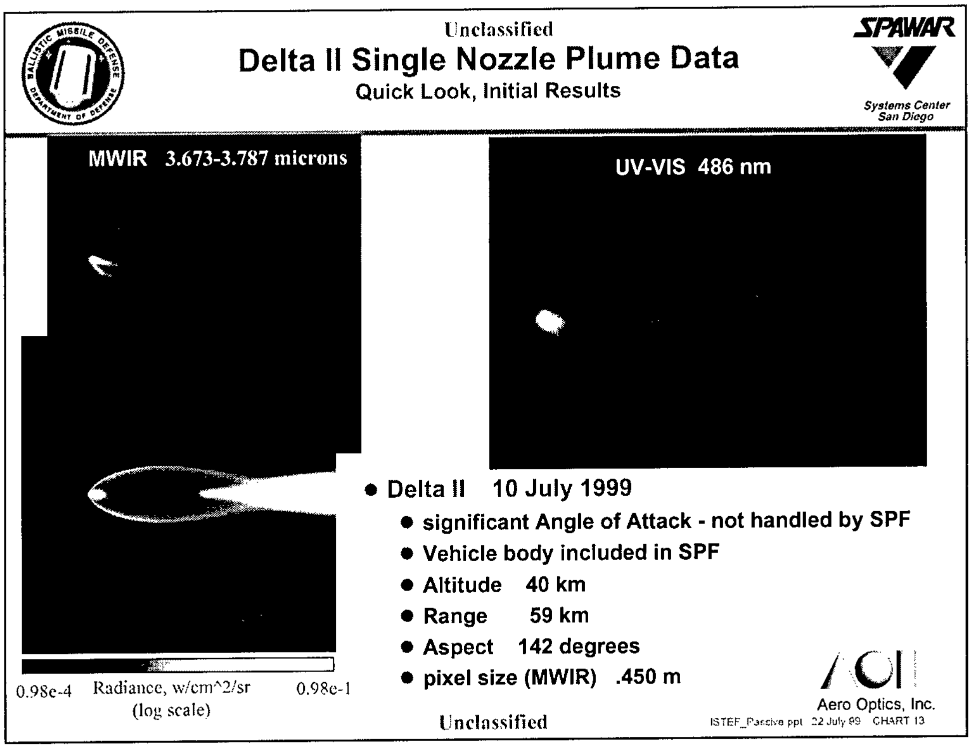
- 197.411 sec. TAL
- 97 km Altitude
- 222 km slant range
- Radiance in $\times 10^{-4}$ W/cm^2 sr
  - outer plume: 2.97
  - rings: 3.01
  - radial rays: 3.16
  - pulse: 5.03



Unclassified

Dynamic non-uniformities within the plume become more significant at higher altitudes as the plume spreads and its radiance decreases. The events are asymmetric, moving rapidly outward and down the plume.

These events are thought to be the result of significant accumulations of soot breaking free from the turbo pump exhaust. The sustainer motor design on the Atlas II vents the exhaust evenly around the outside of the nozzle near the exit plane, in order to reduce asymmetric thrust. The resulting events are distributed randomly around the plume.



Preliminary results are shown for recent data gathered on a unique Delta II configuration and trajectory allowing observation of single nozzle plume beginning at 20 km altitude.

This data at 40 km altitude was collected as the vehicle was experiencing a planned period of relatively high angle of attack due to ground safety requirements. Asymmetries apparent in the plume, especially in the UV-VIS image, are thought to be a direct result. The images are in sensor intensity counts, to be converted to radiance units as data reduction and analysis proceeds.

The SPF/SIRRM prediction included the vehicle body, but the current version does not allow input for angle of attack. The known under-prediction for plume width appears to hold here. Please note the model prediction is represented in log scale, limiting comparison here to structure.

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Examples of Missions Covered by ISTEF Mobile Mounts

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Mission	Tracking Mount	Location
THAAD FT-08	KTM	WSMR
Navy LEAP (FTV-3 & FTV-4)	NRL	Dam Neck, VA
Red Tigress III	KTM NRL	Wallops Island VA Dam Neck, VA
BMDO/DSTO Down Under Black Brandt (DUBB)	KTM	Woomera Missile Range, AUS
BMDO/DSTO Down UNDer Early warning Experiment (DUNDEE)	STRIPS	Anna Plains Station, AUS
Navy SSPO	NRL	Vieques, Puerto Rico
BMDO Sensor Fusion Project (SFP)	KTM, NRL	Cape Canaveral Air Station FL
NASA Cassini	KTM, NRL	Cape Canaveral Air Station FL
Various Atlas, Delta, Titan, & Shuttle	KTM, NRL	Cape Canaveral Air Station FL

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In addition to the boost phase vehicle and plume observations made in the vicinity of ISTEF and the Eastern Range, passive and active sensor experiments have included remote site operations as illustrated by the examples above. Observations have included MDAP development tests, BMDO research tests, and cooperative offshore tests.

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Navy LEAP FTV-04 Mission Results

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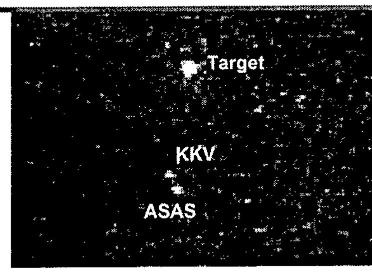
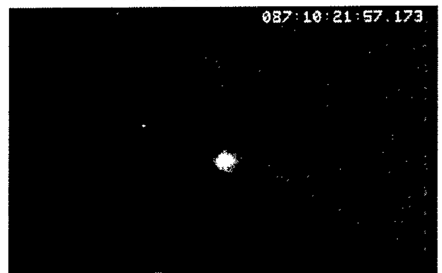
- ISTEF Provided Coverage at Dam Neck, VA
- Successfully Tracked the Target Vehicle from Launch to Horizon
- Provided multi-spectral imagery (visible thru MWIR)
- Attained the best imagery of the KKV and target in the same field-of-view



Intensified visible imagery of FTV-4 KKV, ASAS, & Target

MWIR



Intensified visible

Images are immediately following booster burnout. Note hot particles in MWIR do not show up in the visible

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BMDO ISTEF Coverage of THAAD FT-08

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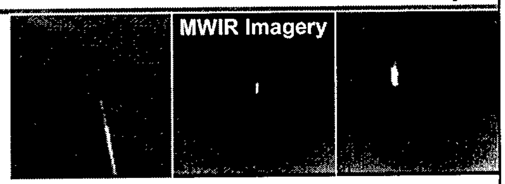
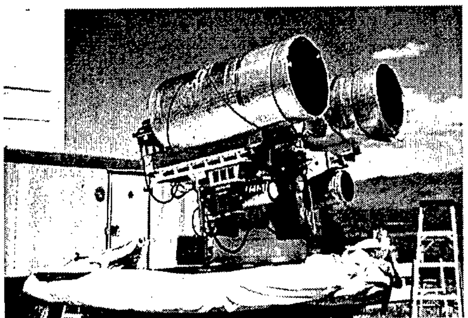
OBJECTIVES

- Collect Calibrated High Resolution UV/VIS & MWIR, LWIR, and Uncalibrated Wide Field-Of-View Imagery Of Target From Launch Through Intercept
- Provide Metric Data For All Objects Under Track: Pre-Impact and Post-Impact



RESULTS

- Successfully Collected High Quality Wide and Narrow Field-of-view UV/VIS, MWIR and LWIR Imagery Of The HERA Target Vehicle Per Tasking Requirements (THAAD FT-08 MRD)
  - Weather conditions were very clear and slightly breezy
  - Failure of one of two elevation drive motors during mount checkout caused irregular track, but did not prevent good data collect
  - HERA was acquired at horizon break during boost phase and tracked continuously until breakup
  - Target tracked through re-entry and partial break-up observed



KTM configured with twin 24" aperture telescopes

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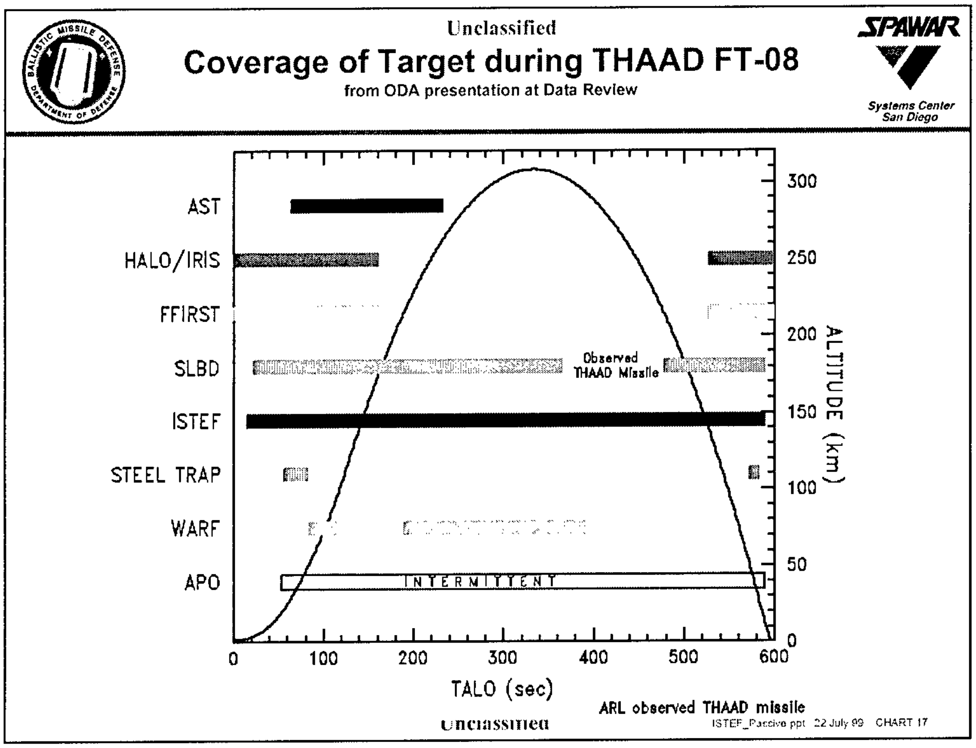
Unclassified
Coverage of Target during THAAD FT-08
from ODA presentation at Data Review
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Systems Center San Diego
AST
HALO/IRIS
FFIRST
SLBD
ISTEF
STEEL TRAP
WARF
APO
INTERMITTENT
Observed THAAD Missile
ALTITUDE (km)
TALO (sec)
ARL observed THAAD missile
Unclassified
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DUNDEE Target Vehicle: Terrier-Improved Orion Sounding Rocket

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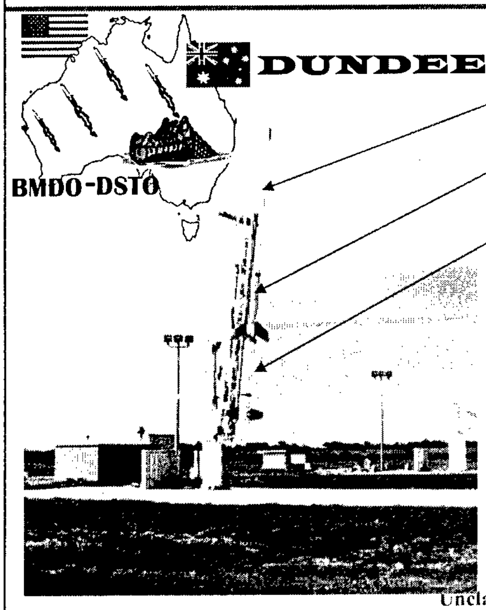

- 10 meter Unitary Target
  - Extended Payload Section
    - 0.2 m dia. X 7.16 m length
  - Improved Orion Second Stage
    - 0.36 m dia. X 2.84 m length
    - Dual thrust Hawk motor
- Terrier First Stage (0.46 m dia.)
- Length: 15.7 m
- Apogee Altitude: 180 km
- Range: 120 km

EVENT	TIMELINE (seconds)	Altitude (km)
Launch (Zero Time)	0	0
First Stage Burnout	+5.2	2.3
Stage Separation	+5.5	2.7
Second Stage Ignition	+18	10.4
Second Stage Burnout	+44	44.4
Apogee	214	179.3
Ballistic Impact	+420	0

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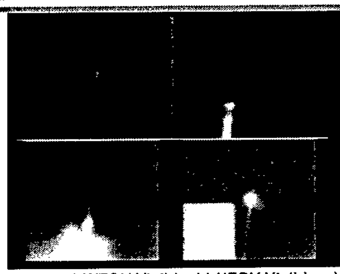
Unclassified

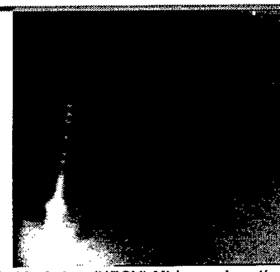
Unclassified

DUNDEE Mission 3

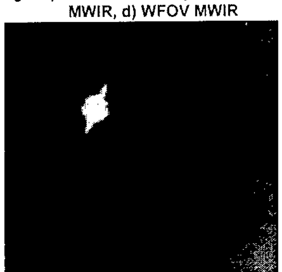
a) b) c) d)



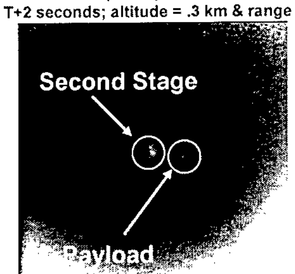
Quad Image: a) WFOV Visible, b) NFOV Visible, c) NFOV MWIR, d) WFOV MWIR



Narrow field of view (NFOV) Mid-wavelength (MWIR) image at T+2 seconds; altitude = .3 km & range = 9.4 km



Narrow field of view (NFOV) Mid-wavelength (MWIR) image at T+25 seconds; altitude = 17 km & range = 19.8 km



Narrow field of view (NFOV) Mid-wavelength (MWIR) image at T+402 seconds; altitude = 114 km & range = 118 km

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FY98,99 Missions (Partial List)

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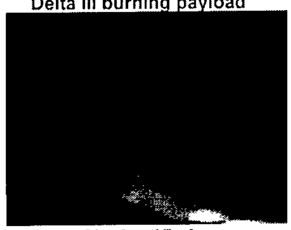
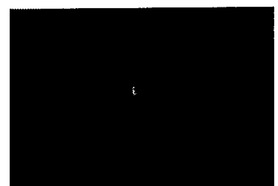
- Navy TMT-2 & TTV-1 - 18 & 20 Nov 1998
  - Provided PMRF with interim capability to collect high resolution long range calibrated MWIR imagery
  - ISTEF large aperture telescope and calibrated MWIR camera installed onto PMRF optical racking mount
  - ISTEF provided sensor operator and experienced mount operator during launches
  - Limited MWIR plume imagery collected during missions due to local clouds
- Delta III Inaugural Launch Failure - 26 Aug 1998
  - Mission coverage as launch of opportunity
  - High, medium and low resolution Visible, NIR and MWIR imagery obtained
  - Provided the only high resolution imagery of payload separating from vehicle and "flying" downrange
  - Video and metric data provided to Eastern Range and Boeing Program Office for failure analysis
- Titan IVA (A-20) Failure - 12 Aug 1998
  - Mission coverage as launch of opportunity
  - High, medium and low resolution Visible, NIR and MWIR imagery obtained
  - Video and metric data provided to Titan Program Office and Eastern Range for failure analysis
- Vehicle Thermal Map Sequence development
  - Shuttle re-entry observation for X33
- DITP Support
  - Phase 1: Demonstrate surrogate components against surrogate target
  - Phase 2: Demonstrate improved capabilities against surrogate target
  - Phase 3: Test individual DITP component(s) with ISTEF surrogate components for tracking/hand over
  - Phase 4: Full brass board tests for tracking/hand over

Delta III explosion (Color Visible)

Delta III burning payload





Delta III explosion, payload ocean impact & explosion (MWIR)

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Collaborations and Support: Navy TBMD at PMRF

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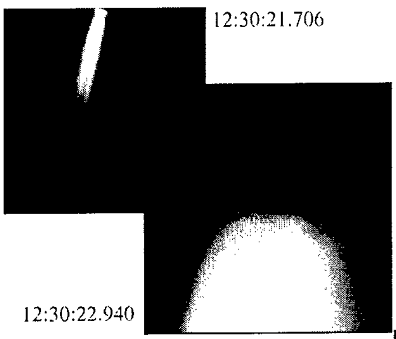
- Example Of Support To Other BMDO Programs
  - ISTEF and PMRF Collaboration for Navy TBMD Area and Theater Wide Program Test & Evaluation events

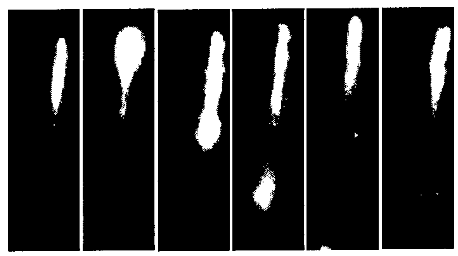
ISTEF support provided to Navy TBMD at PMRF

Mission	Date	Optics	Sensor	Recording	Calibration
TMT-2	11/18/98	24" ap 200" efl	MWIR 256x256	Digital 12 bpp	Black bodies data reduction
TTV-1	11.20/98	24" ap 200" efl	MWIR 256x256	Digital 12 bpp	Black bodies data reduction
SRALT	3/30/99	12.5" ap 150"efl			Black bodies
Slugger	6/30/99	12.5" ap 150" efl			Black bodies

TTV-1, MWIR



SRALT Staging, MWIR



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ISTEF Support to DITP

- Easy access to a surrogate target complex
  - spent Delta strap-on boosters can provide a nice surrogate target.
- Surrogate DITP components
  - ISTEF Can provide surrogate LWIR, MWIR, optics and laser components to aid in system testing
- True system integration testing
  - DITP sub-systems can control ISTEF tracking mount pointing or ISTEF fast steering mirror to "close the loop" for hand-over and discrimination algorithm closed-loop testing
- Ground truth
  - ISTEF sensors can provide metric and radiometric ground truth for DITP testing at Cape Canaveral or elsewhere
- Logistics and manpower support
  - ISTEF can provide manpower and coordinate laser safety and other issues with with test ranges.

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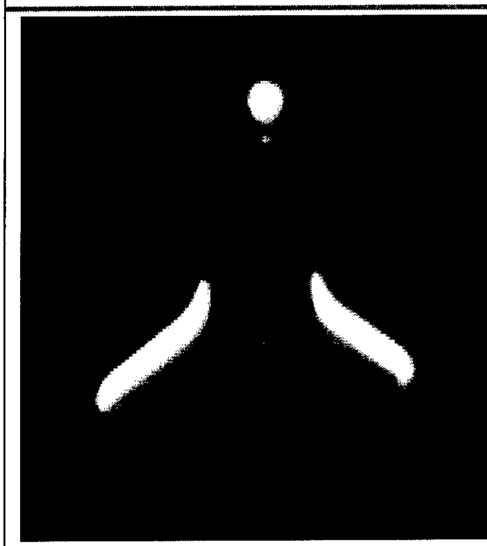
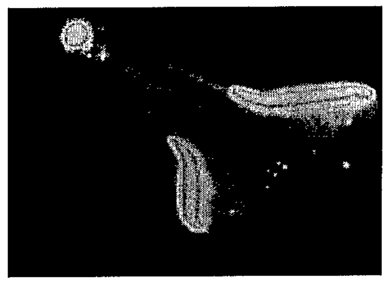
Vehicle Surface Thermal Measurements for NASA X33, Shuttle, and ABL



- Ground observation of boundary layer transition from laminar to turbulent flow
- Product: High resolution thermal map movie sequence for comparison to CFD predictions and wind tunnel results
- Shuttle has been used here as surrogate target to provide data for development of processing techniques
- Application to ABL for scoring and kill assessment



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ISTEF Visiting Experiments

- Motivation
  - Infrastructure
  - Large number of (unclassified) targets of opportunity
  - Expertise
  - Laser radiation approval
    - 1km & 10km ranges
- FY-98:
  - BMDO/TOR (KTAADN) Passive Ranging System
    - Data collected during THAAD FT-08
  - BMDO/TORI (CREOL) Coherently combined receiver laser radar/communications system
- FY-99:
  - BMDO/TORI (JPL) Computed Tomography Imaging Spectrometer (CTIS)
    - Collects two-dimensional imagery and spectra simultaneously
    - Delta II/Stardust 2/7/99
      Collected data on body, solid plume, and liquid plume
    - Delta II/Globalstar-6 12/7/99 (planned)
  - BMDO/TOS Discriminating Interceptor Technology Program (DITP)
    - Three-dimensional laser radar imaging system
    - Integrated Brassboard System
  - Joint BMDO/Israel Data Exchange Agreement
    - ISTEF/Israeli unclassified collections to support DEA Plume Modeling effort
  - BMDO/TORI (JPL) Delta-doped CCD
  - NRC Passive MWIR Polarization Sensor
  - BMDO/TORI (CREOL) Antenna Coupled Focal Plane Array

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Visiting Experiments - General Approach

BMDO sponsored or TMD/NMD/CMD related sensor technology

Opportunities from program cancellations & down selects

Progression of test configuration, goals, and visibility of results

Originator bench tests

ISTEF optics/mount integration and 1km range test

Aircraft/satellites tests at ISTEF site

Boost phase & surrogate target test at ISTEF / CCAFS

Observe major BMDO test at remote range/site
(WSMR, PMRF, Eglin, Barking Sands, Dugway)

Joint responsibilities

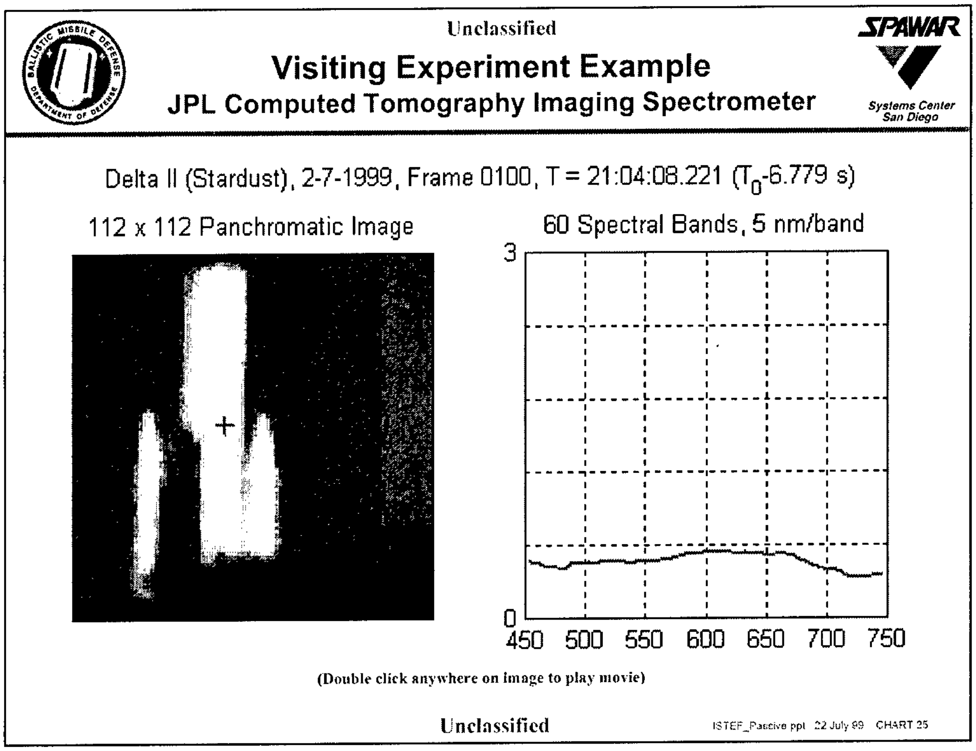
Test Plan, range required documentation

Integration & test schedules and status reports

Mission Quick Look Report with Composite Video Tape

Data Reduction and Analysis

Joint authorship of papers and publications



JPL CTIS data is represented in a movie prepared by JPL. The image on the left is the zero-ith order, where the cross hair identifies the brightest pixel that is selected for display of spectra.

The data set contains spectra for each pixel in each frame of the sequence. JPL has developed tools to display and review the data where the user can select any pixel and view the spectra.

Potential applications include boost and mid-course discrimination, as well as spectral tracking.